Simulation and Classification of Islanding Condition Detection for an IEEE 9 bus system using PMUs and A3C based deep reinforcement learning algorithm respectively

A THESIS SUBMITTED IN FULFILMENT OF THE
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In Electrical Engineering

By

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<u>Certificate</u>

This is to certify that the thesis entitled "**Simulation and Classification of Islanding Condition Detection for an IEEE 9 bus system using PMUs and A3C based deep reinforcement learning algorithm respectively**" submitted by **Millend Roy (Adm. No. 17JE003018)**, in the fulfilment of the requirements for the award of Bachelor of Technology degree in Electrical Engineering at Indian Institute Of Technology (Indian School Of Mines), Dhanbad is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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Millend Roy

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ABSTRACT

With the escalation of energy demands all over and terror of draining conventional fossil fuels, the assimilation of distributed generation networks to centralized traditional networks was introduced. Distributed generation (DG) refers to the production of electricity near the consumption place through renewable energy resources especially wind, solar, tides, biomass, geothermal heat and so on.

Channelizing the field of study, the different problems and issues faced in the trending DG networks has been an interesting topic for researchers where several faults need to be worked upon.

Islanding detection in DG systems is a challenging issue that causes several protection and safety problems. A micro-grid operates in grid connected mode or standalone mode. In the grid connected mode, the main utility network is authoritative for effortless operation in masterminding with the protection and control units, while in standalone mode, the micro-grid operates as a self-reliant and self-sufficient power island that is electrically disconnected from the main utility network. Additionally, without stern frequency control, the equity and harmony between load and generation in the islanded circuit will be disrupted, leading to anomalous frequencies and voltages. Hence different anti-islanding detection methods are studied which reports to the control system how to perform in case of any islanding.

Here basically an attempt is made to build a real time power system with several trending distributed generation systems being installed at the load end and then to monitor the behavior of all the electrical parameters in case of any faults or disturbance. Even cases of islanding are considered and next protection of the power system is also considered by inculcating within different relays and circuit breakers wherever required.

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CHAPTER 1

INTRODUCTION

1.1 Background

Power grid architectonics have emerged remarkably since previous decades, from an unidirectional centralized management approach to a rational and decentralized doctrine which allocate autonomous solutions in administering today's amplifying demand complications. The notion of decarbonizing while boosting electrifications have bricked way for DG technologies to knock the existing power grids, affording a substitute power generation that is handier to consumers. Hence DG is a term that refers to the production of electricity near the consumption place. Solar power generators, wind generators, gas turbines and micro-generators such as fuel cells, micro turbines and so on are all examples of distributed generators. Hence it can be addressed that conventional power distribution systems are passive networks, where electrical energy at the distribution level is invariably outfitted to the customers from power resources which are associated to the bulk transmission scheme.

Advantages of integration of DG resources include substantial environmental profits, enlarged adaptability, restraint of transmission and distribution (T&D) capacity promotion, abbreviated T&D line losses, remodeling power quality, providing better voltage support and so on. However diverse problems need to be tackled before the DG units are applied to the networks. These problems include voltage stabilization, frequency ballast, intermittency of the renewable resources and power quality controversies. Such technical challenges are being resolved by professional engineers and researchers using advanced technologies and power economics.

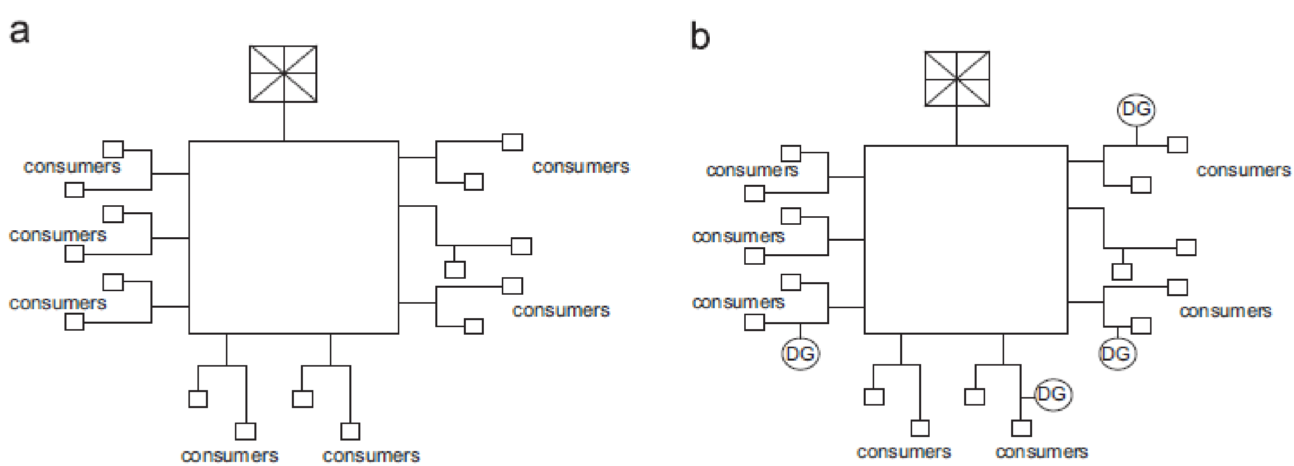


Fig1 Shifting of Technology from Centralized to Decentralized
a) Conventional centralized power distribution system
b) Microgrid network consisting of DG sources at load end

1.2 Definition

Islanding as defined by IEEE standards: - A condition in which a portion of an area of ELECTRIC POWER SYSTEMS (EPS) is energized solely by one or more local EPS through the associated point of common coupling (PCC) while that portion of the area EPS is electrically isolated from the rest of the area EPS.

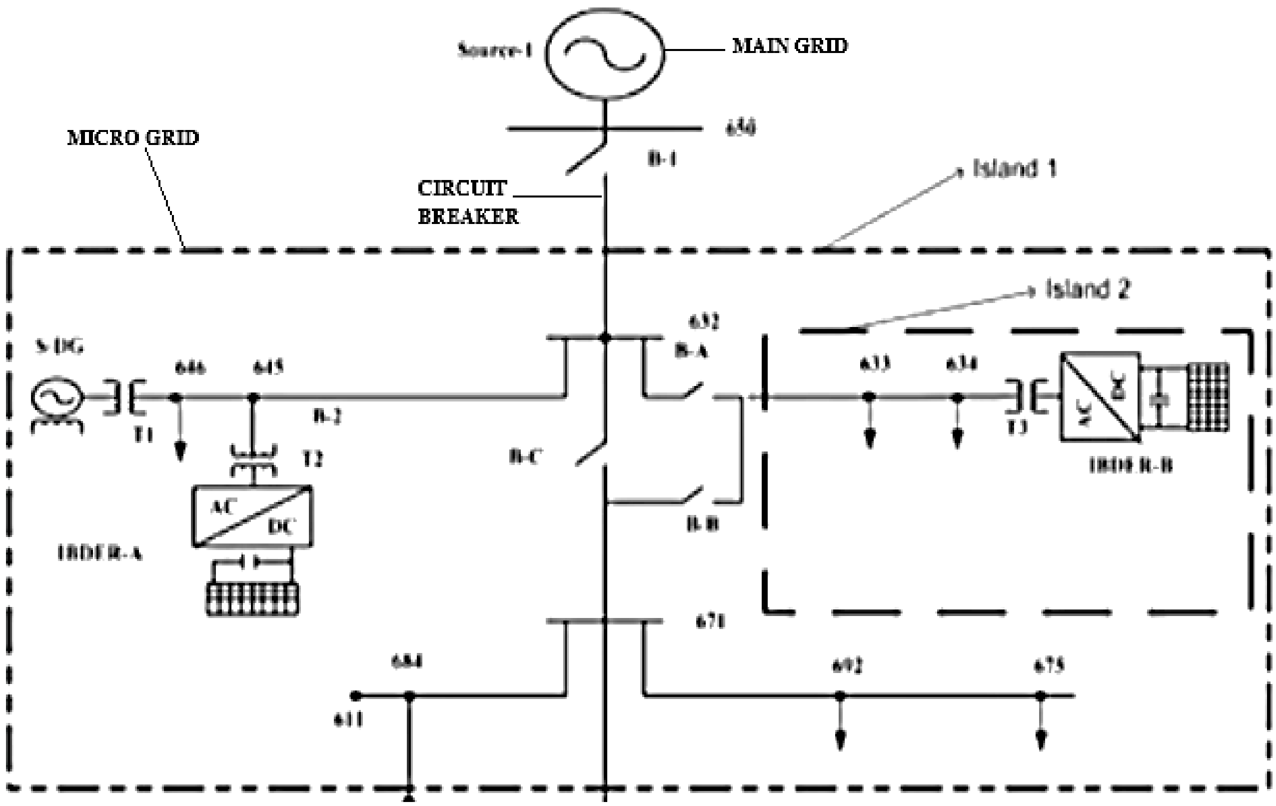


Fig2 Islanded mode operation

An islanding condition can be intentional or unintentional. Intentional islanding is performed due to the obligatory maintenance needed for the main utility, whereas unintentional islanding may occur at any time due to regular faults or other uncertainties in the power system. More about intentional and unintentional islanding can be studied from the following journals.[3] [4]

Unintentional islanding is a threat to power system security. All the problems discussed below adds to it.

- **SAFETY CONCERN**: - As the grid may still be powered in the event of a power outage, due to electricity supplied by distributed generators. Therefore, it may expose utility workers to life critical dangers of shocks and burns who may think that there is no power once the utility power is shut down.
- **DAMAGE TO CUSTOMER'S APPLIANCES**: - Due to islanding and distributed generation there may be a bi directional flow of electricity. This may cause severe damage to electrical equipments and devices. Some devices which are more sensitive to the voltage fluctuations

should be equipped with surge protectors. Now question is what are surge protectors??- Device designed to protect devices from voltage spikes i.e. a transient event, typically lasting 1 to 30 microseconds, which may reach over 1,000 volts. A transient surge protector tries to control the voltage supplied to an electric device by either blocking or shorting current to decrease the voltage under a safe threshold. Blocking is done by utilizing inductors which brings about a sudden change in current. Shorting is achievable by using spark gaps, discharge tubes, zener-type semiconductors, and MOVs (Metal Oxide Varistors), all of which begin to conduct current once a certain voltage threshold is gained, or by capacitors which do not cause a sudden change in voltage. Some surge protectors use multiple elements.

- **INVERTER CONTROL MODE SWITCHING: -** Several inverters are installed with the distributed generators like solar and wind. The inverters have some control strategy and if the micro grid is islanded from the main grid then the PCC voltage, frequency are going to be changed. The control strategy running inside the inverters of different types of renewable resources takes the voltage and frequency feedback from the point of common coupling (PCC). Now if the frequency and voltage of the PCC change, so input to the controller of the inverter change. Therefore, the controller may go to some other mode of operation. Islanding cause problems in proper functioning of the inverters.
- **GRID PROTECTION INTERFERENCE: -** Different types of relay, reclosures, fuses used in grid for protection may mal-operate during islanded mode of operation.

Hence islanding in power networks is a big challenge for protection engineers. As DG integration increases, the need for unintentional islanding detection will be more significant and challenging. Therefore, many new islanding detection methods (IdMs) have been developed to deal with these problems. Furthermore, the standards for intentional and unintentional islanding provide safe operational strategies and overcome the consequences of DG islanding, if properly implemented. For years, many IdMs have been presented, which reveal the fact that islanding is an open research problem.

1.3 Analogy with physical Islands

An analogy is a conglomerate of island banded together by a bridge type link like below. The bridges speak for power lines intertwining sections of the grid. If the bridges are fragmented, then each island would become secluded, both tangibly and electrically. In order for the grid to still operate on the island, it must generate enough power to accommodate load requirements. Each island will possess a contrasting frequency. And when the acquaintances are rebuilt, the two connecting islands must synchronize their frequencies before connecting or both islands will fail.

Fig3 Interlinking of ideas between physical islands and electrical islands

CHAPTER 2

LITERATURE REVIEW

2.1 Existing Islanding Detection Methods

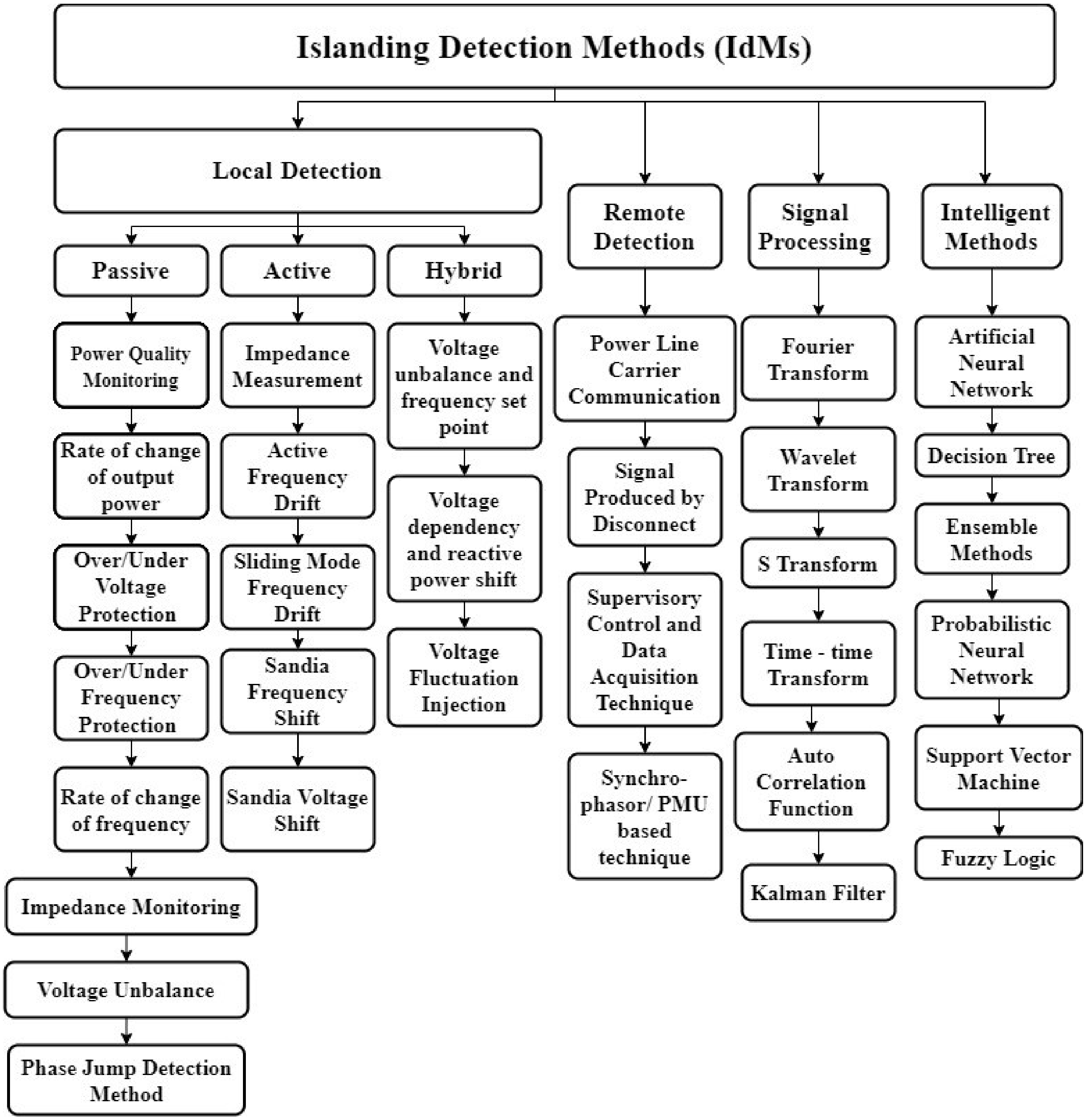


Fig4 Chart showing the different existing Islanding Detection Methods

2.2 Concept of Non-Detection Zone (NDZ)

During islanded mode of operation, main grid is disconnected from the micro grid. Now this does not mean that POWER OUTPUT from the load = POWER GENERATED from the DG sources. This condition is known as power mismatch condition. It totally depends on the mode of operation of the micro grid system i.e., how many loads are switched on or off, how many DGs are in working condition or how many of them are off.

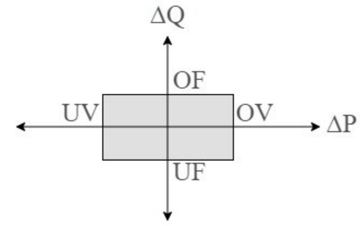


Fig5 Non-Detection Zone

From Fig5,
OV = Over Voltage reach
UV = Under Voltage reach
OF = Over Frequency reach
UF = Under Frequency reach

- ΔP (active power mismatch) = P (active load power) – P (DG active power generation) = P (active power taken or given to grid).
- ΔQ (reactive power mismatch) = Q (reactive load power) – Q (DG reactive power generation) = Q (reactive power taken or given to grid).
- 0% ΔP indicates **P(load) =P(DG)**
- +10% ΔP indicates **P (load) > P (DG)**; the system is loaded and the voltage is going to reduce. Hence under voltage relay is going to experience some tripsing. And if ΔQ is +ve **Q (load) > Q (DG)**, then under frequency relay is going to be actuated.
- -10% ΔP indicates **P (load) < P (DG)**, then over voltage relay is going to be actuated. Similarly, if ΔQ is -ve **Q (load) < Q (DG)**, then over frequency relay is going to be actuated.

NON-DETECTION ZONE (NDZ) defines for what particular percentage of power mismatch the islanding relay does not detect the islanding condition. All the DERs are to be equipped with under voltage and over voltage relays and under frequency and over frequency relays to detect whether the changed voltage and frequency are within the limits or not. According to IEEE standards OVR=1.11 per unit and UVR= 0.88 per unit; OFR=60.5per unit, UFR=59.3 per unit and the islanding detection should be within 1-2 seconds.
The relation between the thresholds of power mismatch and voltage/frequency limits can be derived using the following equations.

- $\{(\frac{V}{Vmax})^2 - 1\} \leq \frac{\Delta P}{P} \leq \{(\frac{V}{Vmin})^2 - 1\}$
- $[Q_f\{1 - (\frac{f}{fmin})^2\}] \leq \frac{\Delta Q}{P} \leq [Q_f\{1 - (\frac{f}{fmax})^2\}]$

Where V_{max}, V_{min}, f_{max}, and f_{min} are the maximum and minimum voltage/frequency threshold limits of the relays in the DG system; ΔP and ΔQ represent the power mismatches prior to the main grid disconnection; Q_f is the load quality factor usually considered to define parallel RLC load.

2.3 Comparison between the islanding detecting methods (IdMs)

Each IdMs has certain advantages and disadvantages.

- Passive methods are simple and can detect the islanding condition using conventional protection methodologies. However, these methods fail to detect the islanding condition when the DG and the load power are balanced, therefore suffering from large NDZ.
- The active methods provide a fast detection speed and small NDZ, but their impact on power quality may deteriorate the performance of the power system.
- Remote methods have fast detection speed, high reliability and the ability to perform well with multiple system configurations. However, the computational efficiency, implementation cost and malfunctioning due to the failure of communication links are the main limitations associated with remote IdMs.
- The signal processing IdMs are becoming more reliable and efficient due to the application of signal processing, pattern recognition and artificial intelligence tools.
- The intelligent methods, due to the presence of various training and testing procedures, suffer from a large computational burden which makes them less favorable in comparison with the other signal processing IdMs.

Therefore, based on the above discussions, it can be observed that the signal processing methods are preferred on the basis of simplicity, cost, low computational burden, accuracy and real-time industrial applications.

CHAPTER 3

PHASOR MEASUREMENT UNITS

3.1 Introduction

Phasor Measurement Units (PMUs) are devices that produce synchro-phasors, frequency and rate of frequency estimates from voltage or current signals received from PTs and CTs and a time synchronized signal which we can get from GPS satellites through GPS clock.

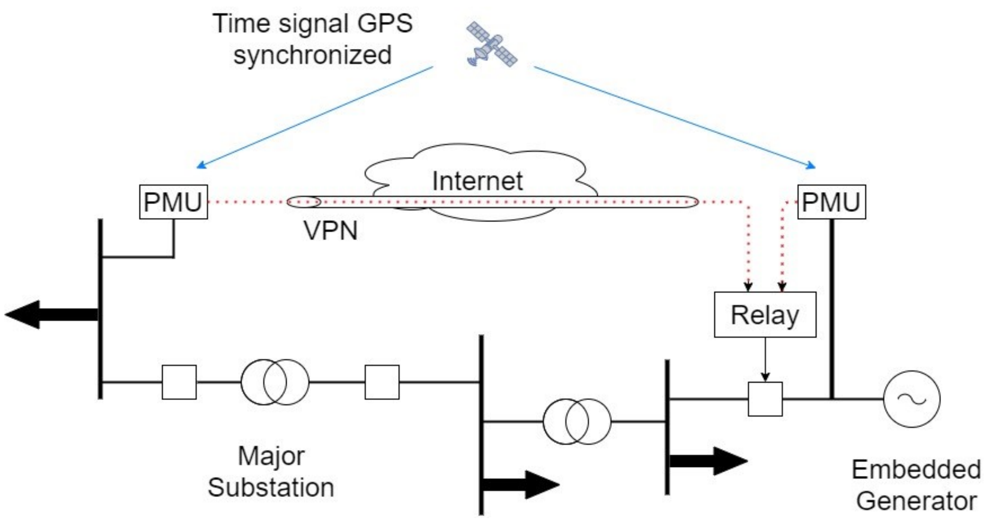


Fig6 Working of PMUs

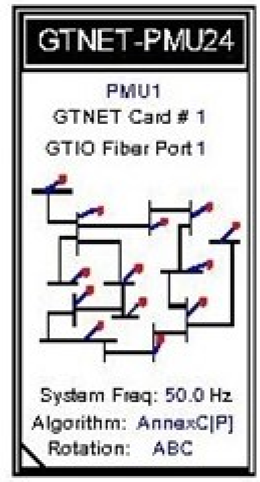


Fig7 PMU block in RSCAD

Fig 6 shows two PMUs are installed one at the grid side and the other at the DG side. Now the data collected about the voltage and currents signals from the PMUs are transferred to the relay which detects any sort of islanding. A circuit breaker is connected which triggers the decision to be taken by the relay.

Now suppose the major substation is disconnected and the breaker on the left-hand side is open. The grid connected voltage phasor consisting of the magnitude as well as the angle is detected by the PMU 1. Similarly, the DG connected voltage phasor is detected by the PMU 2. These data are sent to the relay where comparison is done either based on the magnitude or based on the phasor angle or frequency. Disconnection indicates un-stabilized changed voltage and frequency which triggers the circuit breaker to open.

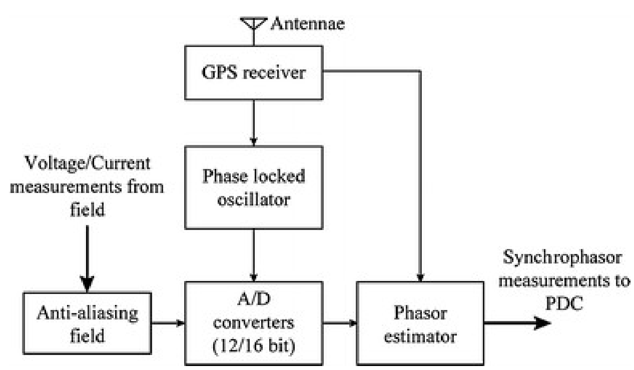


Fig8 Block diagram showing the inside functionalities of a PMU

Therefore, to study and monitor the real time data obtained from the simulation, PMUs are required. The existence of PMU block in RSCAD (Fig 7) helps to collect data and feed to PMU CONNECTION TESTER, where it is checked whether all the PMUs used in the simulation are exporting data or not. Next the data collected is put to the OpenPDC Manager, where all these are converted to an excel file from where they can be assessed and analyzed.

3.2 Comparison with SCADA

1. The most important factor is **how fast the data is being transferred** from SCADA to the EMS. Typically, the output data rate of SCADA has been once in 4-6 secs i.e., data fed to the algo get the data every 4-6 secs.

   If some disturbance takes place, and if one has to study those disturbances or has to study how the system behaves after the disturbance (post disturbance analysis) then if the output rate is just once in every 4-6 seconds, then probably that is not enough. Because the power system tends to change very quickly; it's a dynamic system, so if we are not able to capture the values of power system in a good percentage, then we lose our data. Therefore, we are not able to view the exact behavior of the power system and if the exact behavior is not extracted, then there might be a chance of ending up with wrong control actions.

   As a result, data is required at a much faster rate that helps to stagnate and apply all the numerical values of data. From here to eliminate this disadvantage emerges a new technology named synchro-phasor.
2. In SCADA, we are trying to gather data from different parts in power system and even though the data might have some timing, but the problem is sending data to a control center and some other substation located quite far away and is getting to send the data as well to the same control center, because of the **geographical distance** the substation which is closer will get to send the data much quicker than the other substation. Hence local clocks are used to stand the data coming from the local substations; so that we get to know what time those data belong to. So, time synchronized wide area system data is required to have an accurate view of the entire power system.
3. SCADA tech. gives **just magnitudes** of different electrical quantities like voltages, currents, frequency and so on. Networks one has to analyze are AC which has both magnitude as well as angle phasors. Therefore, looking into just magnitude leads to loosing of information and ending up monitoring the system wrongly.

Because of all the above reasons, PMUs are gaining much popularity nowadays.

CHAPTER 4

MODEL BUILDING METHODOLOGY

4.1 Overview of the Research Procedure

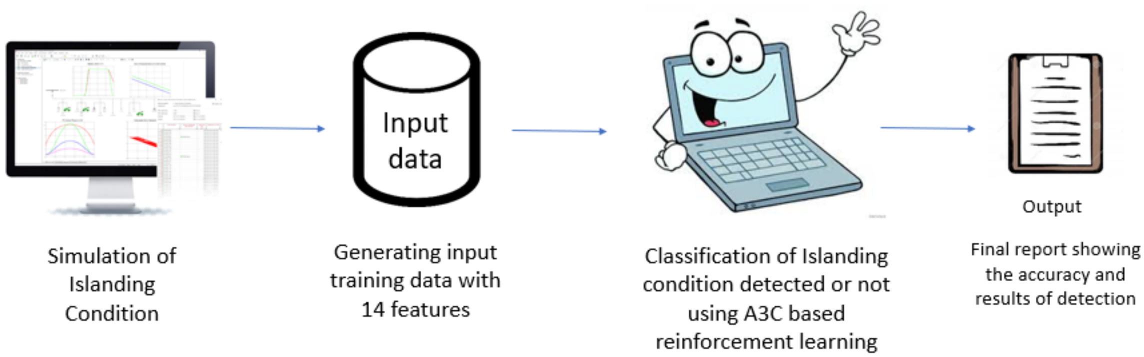


Fig9 Diagram representing the workflow of the research procedure

Firstly, the islanding condition is simulated in RSCAD software which acts as an interface for Real-Time Digital based Power System Simulator (RTDS) using PMUs which help to capture the essential electrical quantities.

Next, this data is retrieved in excel format so as to perform data analysis on it.

A classification model is built using Asynchronous Advantage Actor Critic (A3C) based deep reinforcement learning algorithm which gets trained on the generated data from the simulation model.

Finally, a report is prepared showing the accuracy and results of detection.

4.2 Knowing about RTDS and RSCAD Software Handling

RTDS is a real time power system simulator, which employs an advanced, and easy to use graphical user interface. The RTDS allows users to accurately develop their models and simulate them efficiently. The software used to architect the power system model in RTDS is RSCAD, which involves a library of power and control system components. RSCAD permits the developer to choose a pictorial portrayal of the power system or control system components from the library in order to design the needed circuit. Once the system has been drawn with the entry of required parameters, the compiler in RTDS generates the low level code that is needed to perform simulation on the RTDS simulator. RTDS is capable of generating the real time signals, which enable the user to simulate the situations, which generally occurs in the power system.

RSCAD is software which permits the user to develop a test case by using the numerous different components present in the RSCAD library. The following steps are required to prepare and run a new simulation case.

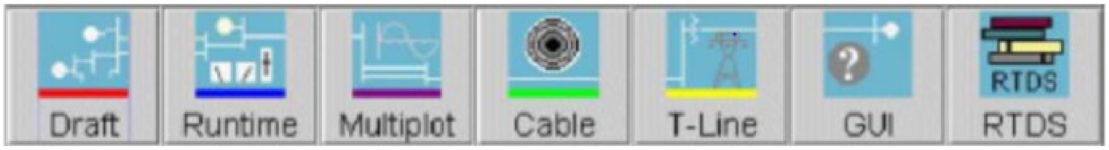


Fig10 Options available on opening RSCAD

- The RSCAD/Draft software module is started.
- A new ‘Project’ and ‘Case’ directory is created in the ‘File Manager’ module.
- Next the new circuit diagram is created for simulation and the circuit is compiled.
- Lastly the simulation case is opened from RSCAD/RunTime.

The RSCAD/Draft software module is used to build the circuit that will be simulated employing the RTDS simulator.

Fig11 Options available on draft window

After the successful compilation of the system, the user simulates the system by using the RSCAD/ RunTime software module.

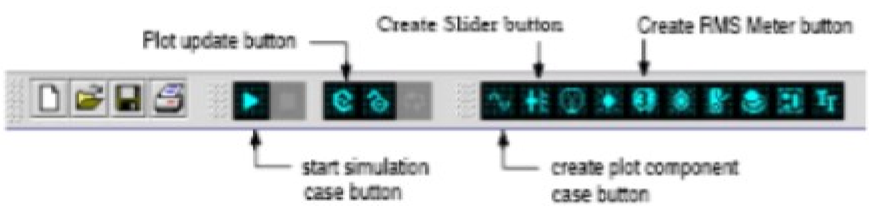


Fig12 Options available on runtime window

In RunTime mode, the user is able to add switches, buttons, meters and sliders for fault application, can plot graphs for voltage, current, power, fault, and frequency etc., can increase or decrease different physical quantities. After completion of the selection of plots in the RunTime, the user is able to simulate the system by pressing a button “Start Simulation” which is available in the RSCAD/RunTime module.

4.3 Fault Control Logic

Electrical systems occasionally experience several types of faults. These faults are hazardous to the safety of both equipment and people. Faults in a 3-phase system can be unsymmetrical: -single line to ground, double line to ground, line to line or three phases symmetrical. Power system operation during any of these faults can be analysed using sequence components discovered by Charles L. Fortescue.

- **Symmetrical Faults: -** Before the fault, voltage and current were 120º phase displaced and balanced i.e., magnitudes of all the phases were same. Even after the fault, voltage and current magnitudes and phases remain balanced. Therefore, this type of faults is known as symmetrical faults. Now faults can be either short circuit (L-L-L) or ground (L-L-L-G) faults.
- **Unsymmetrical Faults:** - Before the fault, the system is in balanced condition, but after sudden faults, they become unbalanced. Specifically, line to ground (L-G), line to line (L-L) and double line to ground (L-L-G) faults are common.

Fortescue Theorem states that if there are n unsymmetrical phasors, then these phasors can be resolved into n-1 symmetrical phasors and 1 co-phasal quantity. Since here discussions are related to current and voltage vectors, therefore there are only 3 unsymmetrical vectors which can be divided into 2 symmetrical vectors and 1 co-vector.

Now since faults can be permanent or temporary i.e., transient for a short period, hence for the simulation purpose both the faults have been considered.

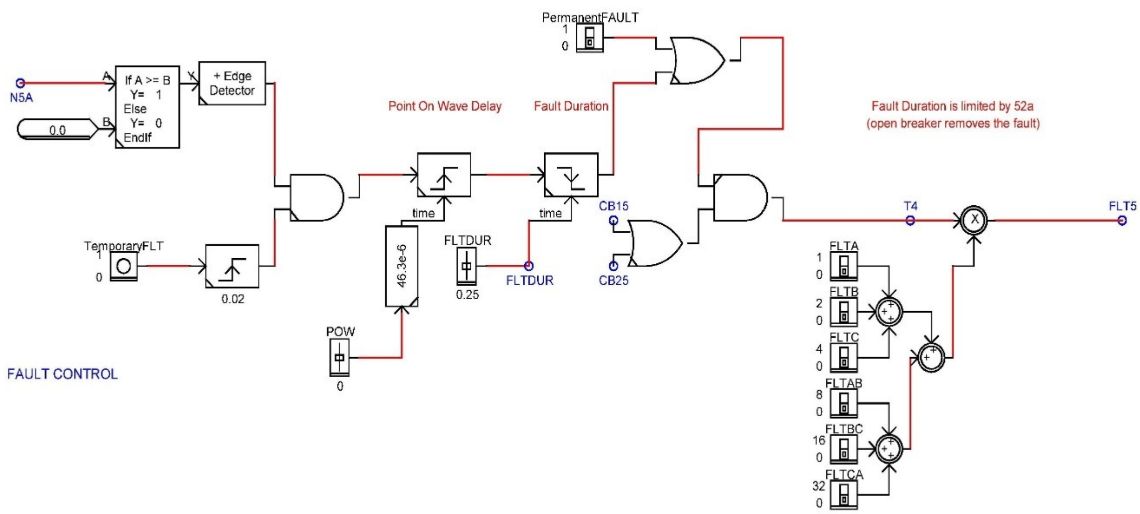


Fig13 Fault Control Logic

4.4 Protection Relay Blocks and Logics

In this article main focus was to protect the transmission and distribution lines from faults, hence certain type of relays comes into picture which helps us to attain so. Distance relay with directional features specifically MHO relay is mainly used in the transmission lines with overcurrent directional relays and differential relays in the distribution lines. RSCAD provides the facility to use their inbuilt models of distance protection components.

a. **Distance Protection: -** It depends upon the distance of feeding point to the fault. The time of operation of such a protection is a function of the ratio of current and voltage i.e., admittance or voltage and current i.e., impedance. Since MHO relay used; is an admittance relay, therefore discussions related to it are more specific in this report. MHO relay is a high speed relay and is also known as angle impedance relay. In this relay administering torque is purchased by the volt ampere element and the restraining torque is refined due to the voltage element. Therefore, an MHO relay is a voltage restrained directional relay. The equation of the torque can be given as: -

i. $T = K1VI \cos(\theta-\tau) - K2V2 - K3$ where K3 is the control spring effect and θ and τ are defined as positive when I lag behind V. At balance point:-
ii. $0 = K1VI \cos(\theta-\tau) - K2V2$ (considering spring effect as 0)
iii. $K1VI \cos(\theta-\tau) = K2V2$
iv. Therefore, $Z = K1/K2\cos(\theta-\tau)$ which reflects an equation of a circle passing through origin whose diameter is $K1/K2 = ZR$ (ohmic setting).

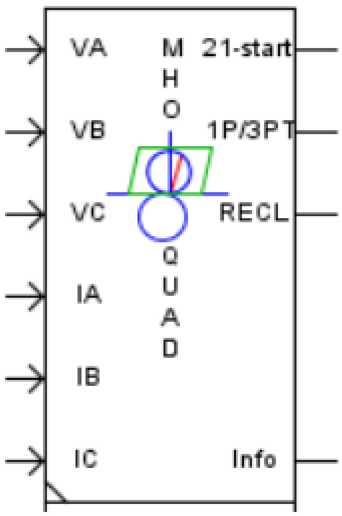


Fig14 MHO Relay block in RSCAD

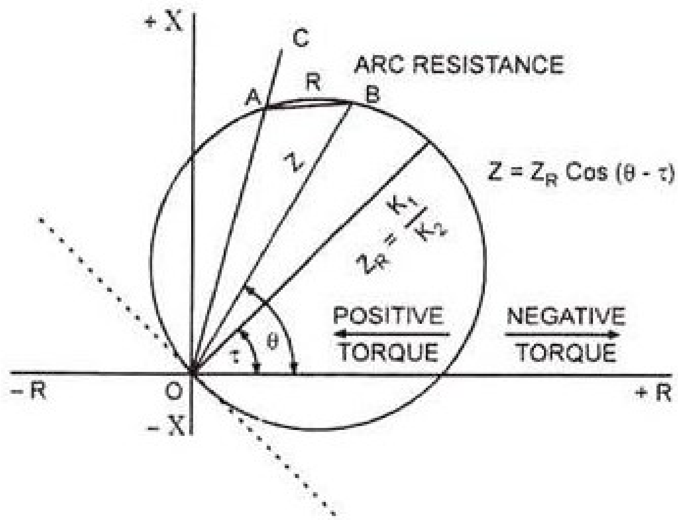


Fig15 Operating characteristics of MHO Relay

In Fig 14, the inputs to the component would be the voltages and currents of different phases detected by the secondary of CTs and PTs connected in the main transmission lines. Whereas the output will be in the form of WORD that needs to be converted to BITs to be accessed by other logics.

Therefore, the logic used here is such that it compares the admittance or even impedance with the threshold zone impedance already set inside the relay. If the impedance comes out to be less than the set impedance then it can be concluded that fault has occurred in that zone due to increase in current flow.

b. **Overcurrent Relay Protection Logic:** Similar to distance protection, here too a comparison is made between the rms current flowing through the transmission lines and the setting threshold values. If the values move on to a higher pitch than the threshold then over protectional relays help to trip the corresponding circuit breakers by sending the trip signal. The logic used has been shown below.

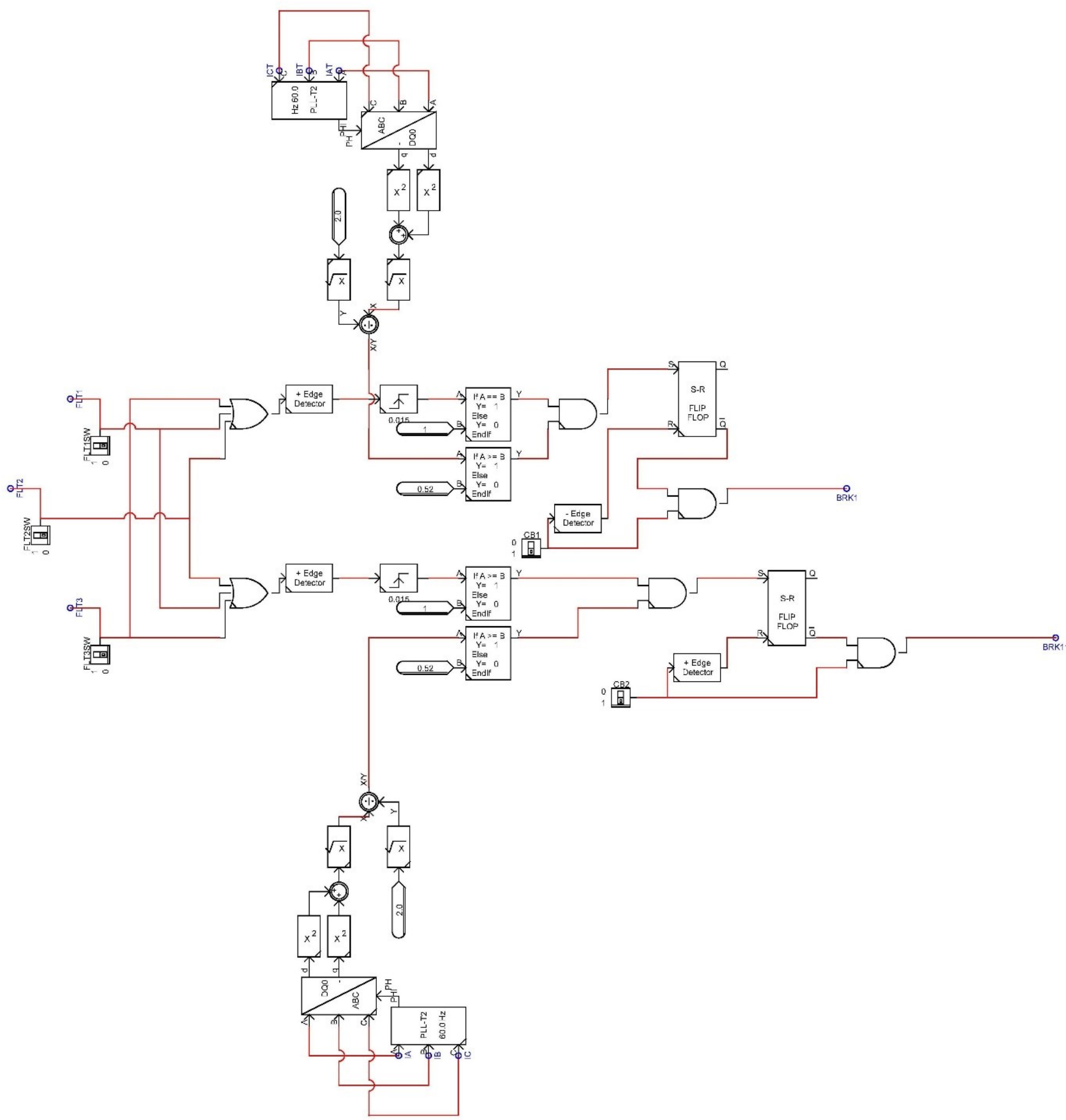


Fig16 Overcurrent Relay Protection Logic

4.5 Load Variation

Since all the simulation is done on real time, hence it would be better if the load is varied and how synchronization is done by the power generators are observed. Synchronization involves voltage and current magnitudes and phasors as well as frequency.

Generator takes mechanical energy as input and gives electrical energy as output which is equal to load requirement. Now if suddenly load is increased by 10%, at this instant electrical energy required is more than the mechanical energy provided. So, stored rotational kinetic energy in rotor of generator is converted to supply excess electrical energy.

N_S=120*f/P where N_S is the speed of the rotor, f is the frequency and P is the no. of poles of the Machine.

Now suppose electrical generation exceeds load requirement which indicates that N_s is more and so frequency generated is more which is to be brought down by slowing down the rotor speed and maintained at reference. Similarly, the opposite happens when electrical generation is less than the load requirements. In this way frequency synchronization is done.

Now Load data is taken from an official NYISO which has an excel sheet that contains varied load after every 5 mins in 11 different regions. (https://www.nyiso.com/load-data) This excel data has to be fed in the RSCAD model where simulation is to be done. Now data can only be fed through port. So using UDP protocol and writing code in Python, data are sent to the required ports from where they are accessed.

4.6 Final Model

1. First of all the model is built i.e. connecting utility grid as well as microgrid from the draft window in RSCAD and the transmission lines data are fed from the T_Line window by specifying the length and positive and zero sequence impedances as required.
2. Next the faults are made to occur in the transmission lines depending on what type of fault user needs to watch in the runtime window of the simulation. It may be a permanent fault provided by a switch or a temporary fault provided by a push button.
3. Next signals from CTs and PTs are sent for sampling the voltage and current signals and then put into DFTs to extract samples of 60 Hz component.
4. PMUs detect these data wherefrom the extracted data are sent to relays where decisions are made what step next to be taken and send them accordingly to the circuit breakers.
5. When the Circuit breakers open from the utility grid, the microgrid becomes islanded as during fault; frequency, current and voltage magnitudes and phasors are not synchronized. Due to lack of synchronization circuit breakers receive the trip signal from relays and get disconnected.
6. The time period for disconnection may be a short period if temporary fault occurs. If permanent faults occur then first the circuit breakers trip, then again reconnect after certain time interval hoping that the fault has cleared. When they find that the fault has not cleared, they open once again and it continues for a total of 4 times until they quite surely understand that the fault occurred is permanent and locks the breaker in the open position for the rest period of time. Workers from maintenance have to come and clear the fault and close the breakers to ensure continuity of power flow.

Now during islanding a small checking is done which turns out to be quite helpful at the end. The load requirement and the power generated from the DG resources are compared. If load requirement is less than the power generated quickly a communication signal is sent to the inverter to shut the DG since this may burn the other home electrical appliances and even may trace back to the faulty transmission line location where the maintenance workers are working and may threaten their lives. If the load requirement is more than the DG, then do the necessity so as to synchronize and turn other DGs on if available else continue the DG to operate in low voltage operation until power from grid returns.

The 9-bus model used in the simulation is shown below: -

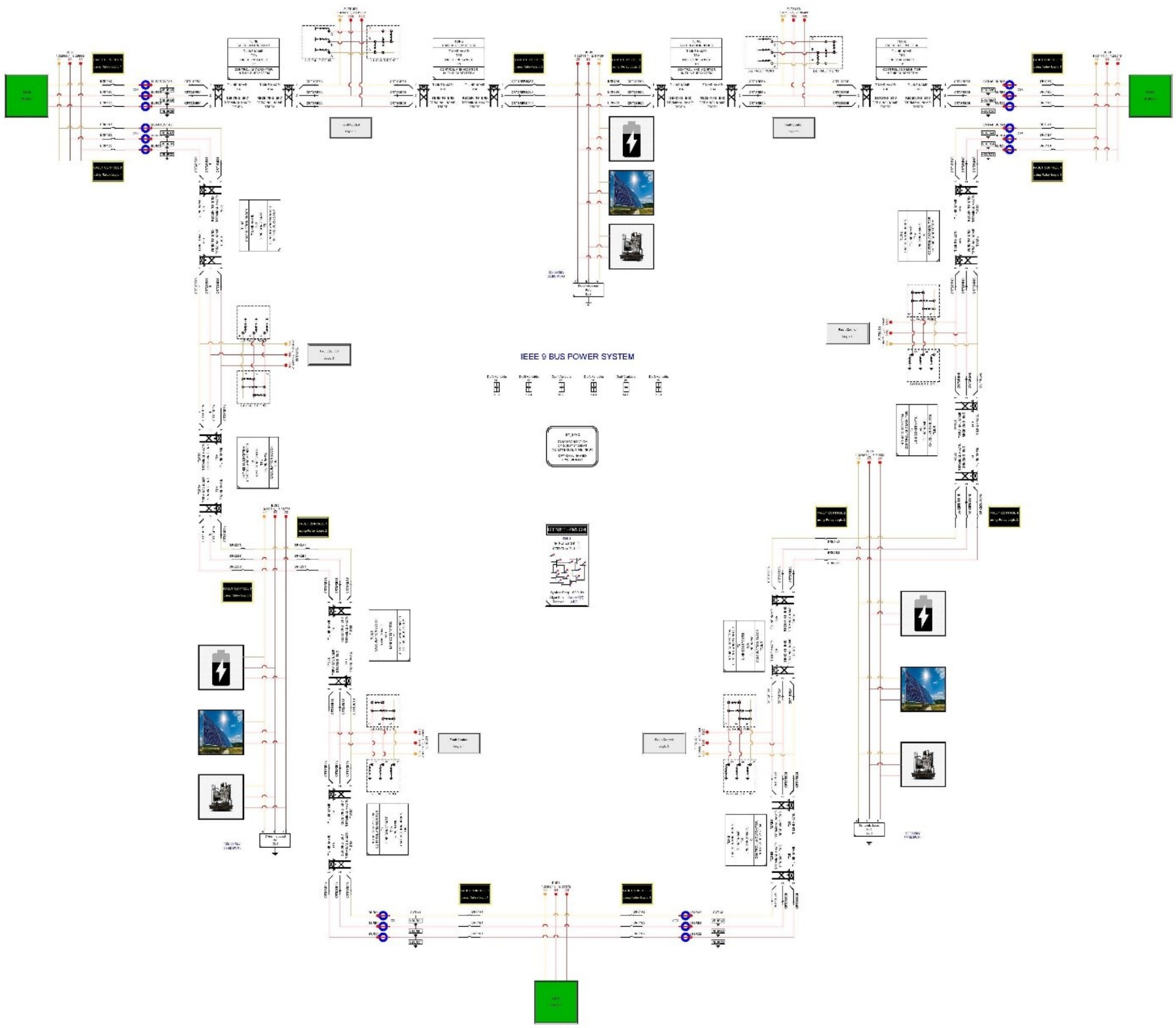


Fig17 Final 9 bus power system model with DG Sources installed

4.7 Data Generation Procedure

Methodology of time series data generation:

1. Fault resistances varied across all the faults and data was collected. Fault Resistances = {0.1, 10, 20, 30, 40, 50, 60}
2. Faults made to occur at different bus positions. Fault loc: {7-8, 8-9, 7-5, 5-4, 9-6, 6-4}
3. Types of faults: {AN, BN, CN, AB, BC, CA, ABN, BCN, CAN, ABC}

Total time captured = 0.7 seconds
Fault duration =10 cycles =10/50 = 0.2 seconds.

Data Produced for each case = 7,00,000
Total data = 7 (fault resistances) x 6 (fault locations) x 10 (types of faults) x 7,00,000 (time series data per case) = 29,40,00,000

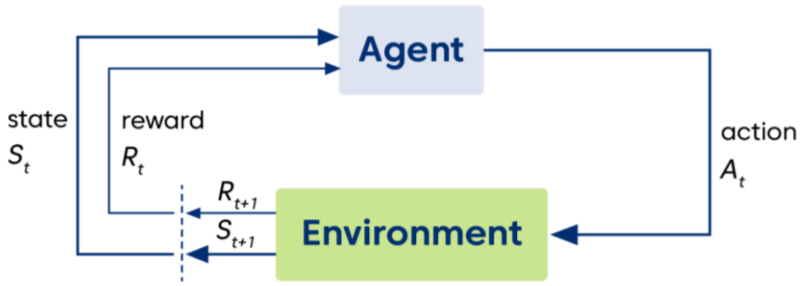
Features:

1. Current in phase A= IA,
2. Current in phase B= IB,
3. Current in phase C= IC,
4. Voltage in phase A= VA,
5. Voltage in phase B= VB,
6. Voltage in phase C= VC,
7. Frequency= f,
8. Rate of change of frequency= ROCOF,
9. Phasors of IA,
10. Phasors of IB,
11. Phasors of IC,
12. Phasors of VA,
13. Phasors of VB,
14. Phasors of VC

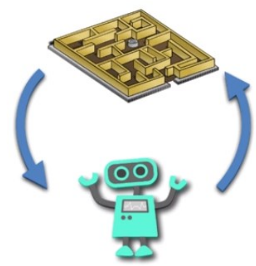
CHAPTER 5

OVERVIEW OF ASYNCHRONOUS ADVANTAGE ACTOR CRITIC (A3C) ALGORITHM

5.1 Introduction of Deep Reinforcement Learning



(a)



(b)

Fig18 (a) Block diagram of a Reinforcement Learning Algorithm, (b) Example of a Maze Runner Bot

Here, for Fig 18 (b), lets consider a Maze Runner bot who has to travel through the maze starting from the initial point and has to come out of the maze from the end point. So, here, the Maze runner bot acts as the agent. The maze is actually the environment. The agent here can take 4 actions i.e., can move straight, can move backwards, can move left and right. Using these actions, it has to traverse through the maze. By taking an action, each position it ends up inside the maze can be called as state. Therefore, based on the actions the agent takes, environment feedbacks a reward which helps it to learn how to proceed next and quantify the action it has taken as bad or good. The main aim of the agent is to maximize the reward, and hence by taking it as the objective it can learn how to navigate through the maze.

So, a reinforcement learning always has these 5 parameters which helps in training of the model. Therefore, in our case, these parameters are as follows:

1. Agent: Here, the AI algorithm- Asynchronous Advantage Actor Critic (A3C) Algorithm.
2. Environment: The Excel file generated from OpenPDC Manager containing the time series data.
3. Action (a): Only 2 things either islanding detected or not, since a binary classification problem. [0,1]
4. State (s): Each row sample in the dataset.
5. Reward: While choosing the values of the rewards, the ratio of the number of majority class elements to minority class elements is used, which is referred as $\boldsymbol{\rho}$.

$$r = \begin{cases} \frac{1}{\rho}, & \text{if correct classification of majority class} \\ \frac{-1}{\rho}, & \text{if false classification of majority class} \\ 1, & \text{if correct classification of minority class} \\ -1, & \text{if false classification of minority class} \end{cases}$$

Here majority class is the non-islanded class, and minority class is the islanded values.

5.2 Actor Critic

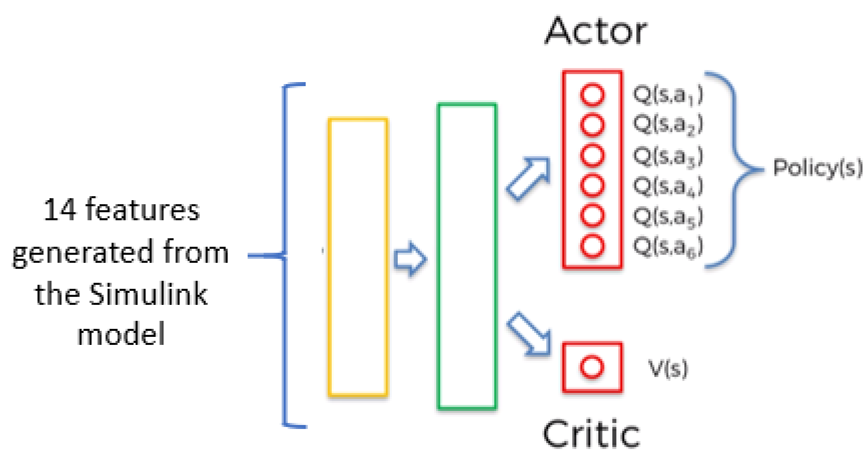


Fig19 Neural Network model representing Actor and Critic

Here, the 14 features describe the input nodes of the neural network. After which the hidden layers and no. of input nodes can be decided using keras-tuner or GridSearchCV. Here, there are 2 types of outputs – Actor and Critic.

Actor denotes the actions, Q(s,a) quantifies the action a taken by the agent in the state s. Here only 2 output nodes will be there denoting Q(s,a1) and Q(s,a2) since in our case, the agent can take only 2 actions i.e. detecting either the case is islanded one or not.

Critic V(s) signifies the value of the state, in which the agent is present currently. Since each row is a state, so every iteration, it takes in one state (which is represented by the 14 features) and outputs the value of the corresponding state.

5.3 Asynchronous

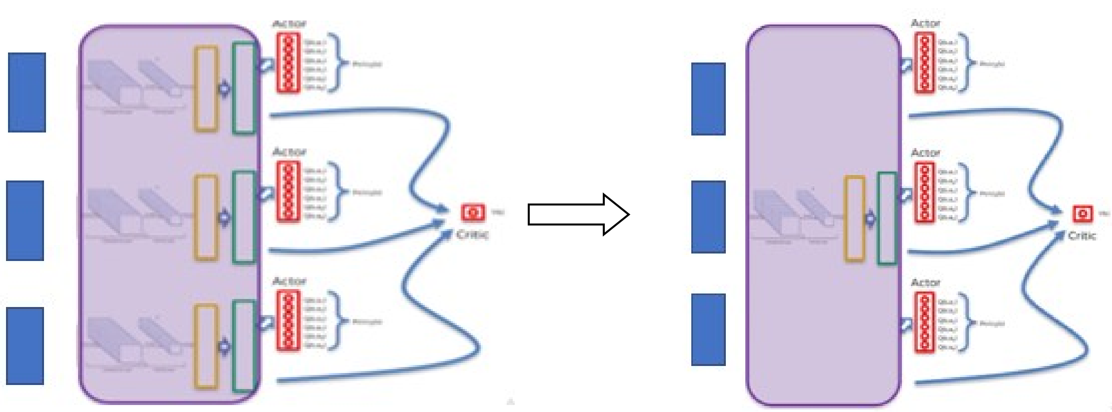


Fig20 Neural Network models representing parallel asynchronous agents

The samples we gather during a run of an agent are highly correlated. If we use them as they arrive, we quickly run into issues of online learning.

So, there should be a process to break this correlation while still using online learning. We can run several agents in parallel, each with its own copy of the environment, and use their samples as they arrive. Different agents will likely experience different states and transitions, thus avoiding the correlation. Another benefit is that this approach needs much less memory, because we don't need to store the samples.

This is called asynchronous since the multiple agents used have different initialization points in the environment (i.e., in our case different starting positions within the excel sheet).

5.4 Advantage

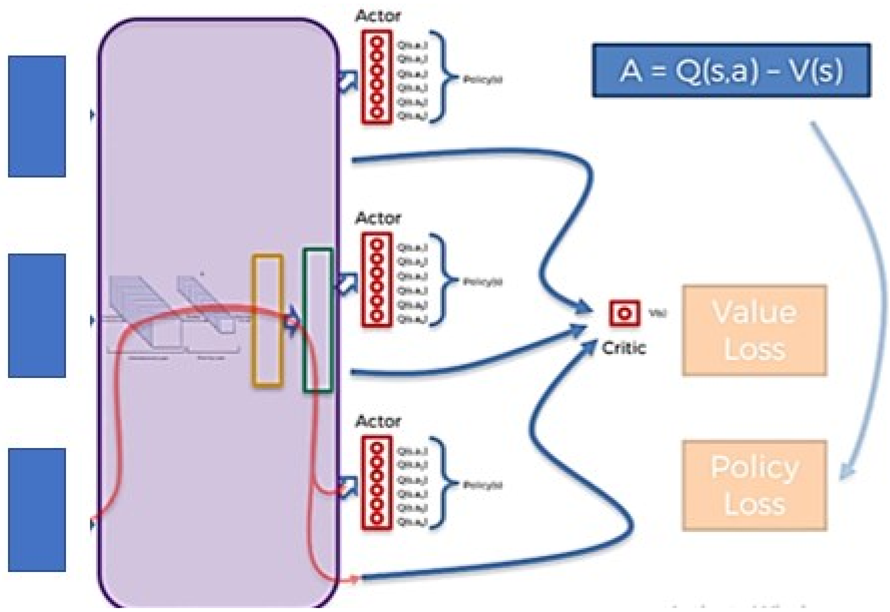


Fig21 Neural Network model representing how losses are backpropagated to update weights

Typically, in the implementation of **Policy Gradient**, the value of Discounted Returns to tell the agent which of it's actions were rewarding and which ones were penalized. By using the value of Advantage instead, the agent also learns how much better the rewards were than it's expectation. This gives a new-found insight to the agent into the environment and thus the learning process is better. The advantage metric is given by the following expression: -
Advantage: A = Q(s, a) – V(s)

5.5 Final Model with addition of LSTM layer

Following is the final model described which has Long short-term memory (LSTM) cells of Recurrent Neural Networks (RNN) present inside it. LSTM cells take care of the time series analysis because of the presence of the memory lane in its structure. The disadvantage of vanishing gradient in RNNs is also eradicated with the addition of LSTM cells.

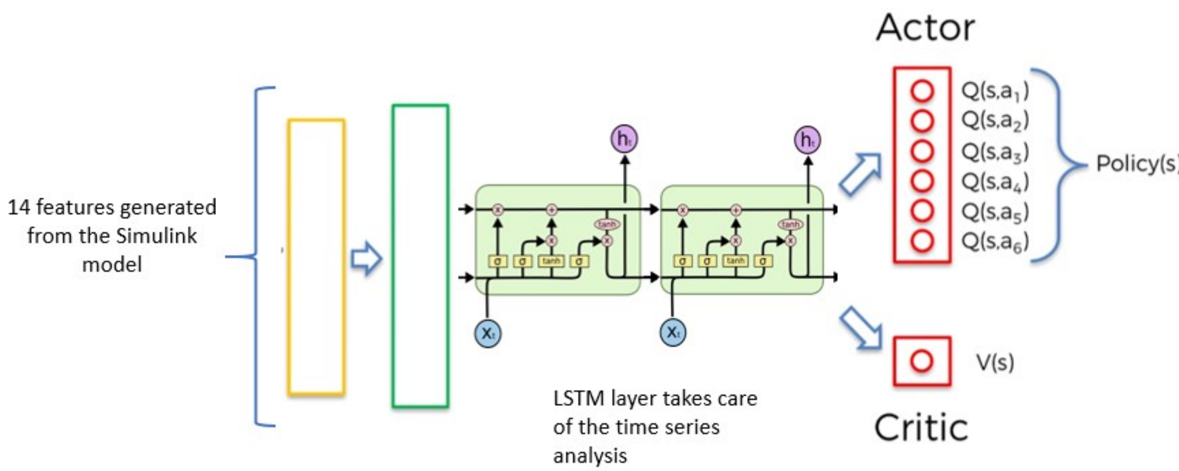


Fig22 Final Asynchronous Advantage Actor-Critic Model

5.6 Pseudo Code of the A3C Algorithm

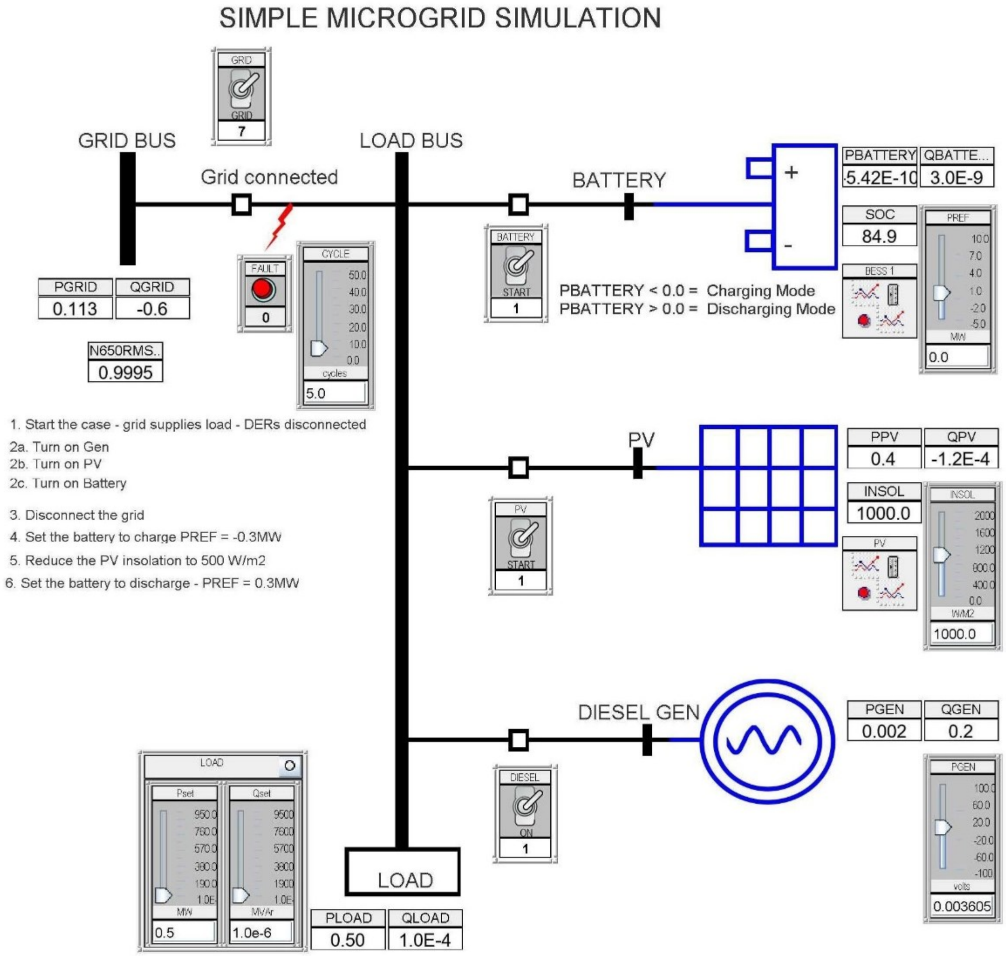
Algorithm 1 Asynchronous one-step Q-learning - pseudocode for each actor-learner thread.

// Assume global shared θ, θ^-, and counter $T = 0$.
Initialize thread step counter $t \leftarrow 0$
Initialize target network weights $\theta^- \leftarrow \theta$
Initialize network gradients $d\theta \leftarrow 0$
Get initial state s
repeat
  Take action a with ϵ-greedy policy based on $Q(s, a; \theta)$
  Receive new state s' and reward r
  $$y = \begin{cases} r & \text{for terminal } s' \\ r + \gamma \max_{a'} Q(s', a'; \theta^-) & \text{for non-terminal } s' \end{cases}$$
  Accumulate gradients wrt θ: $d\theta \leftarrow d\theta + \frac{\partial (y - Q(s,a;\theta))^2}{\partial \theta}$
  $s = s'$
  $T \leftarrow T + 1$ and $t \leftarrow t + 1$
  if $T \mod I_{target} == 0$ **then**
    Update the target network $\theta^- \leftarrow \theta$
  end if
  if $t \mod I_{AsyncUpdate} == 0$ or s is terminal **then**
    Perform asynchronous update of θ using $d\theta$.
    Clear gradients $d\theta \leftarrow 0$.
  end if
until $T > T_{max}$

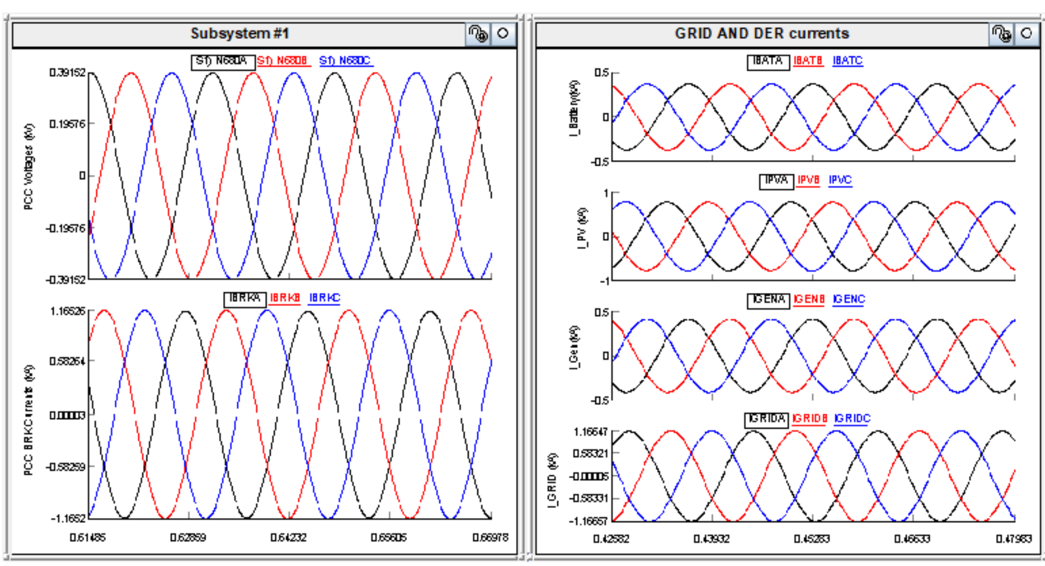
CHAPTER 6

OBSERVATION AND CONCLUSION

6.1 Simulation Results

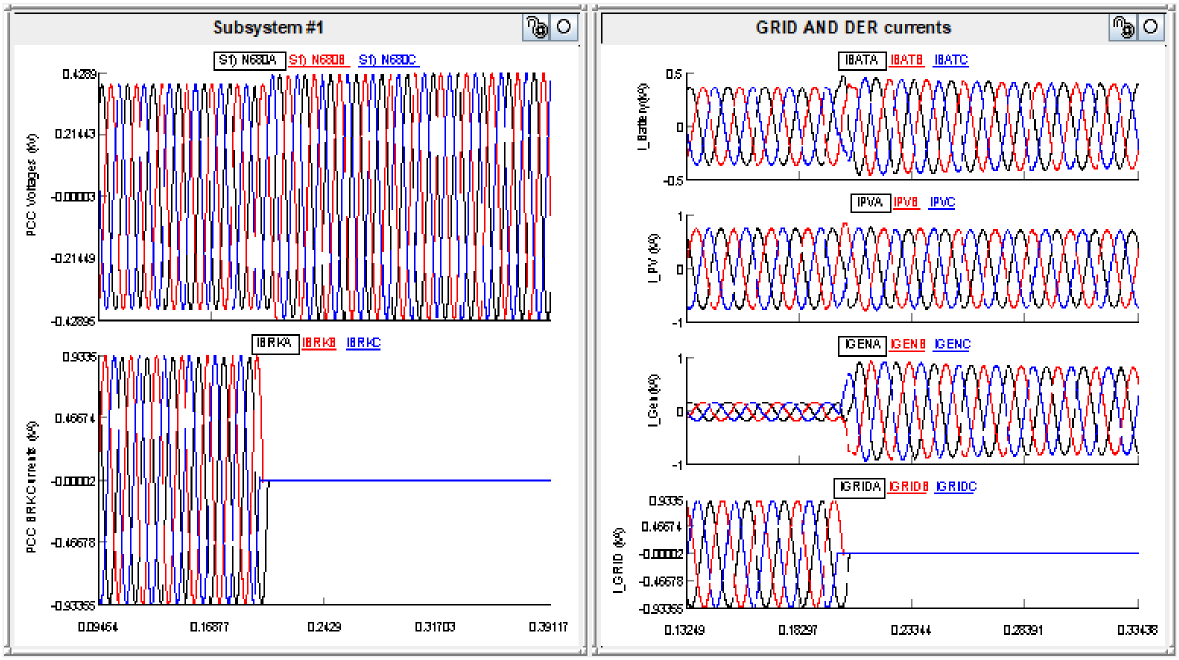


(a)

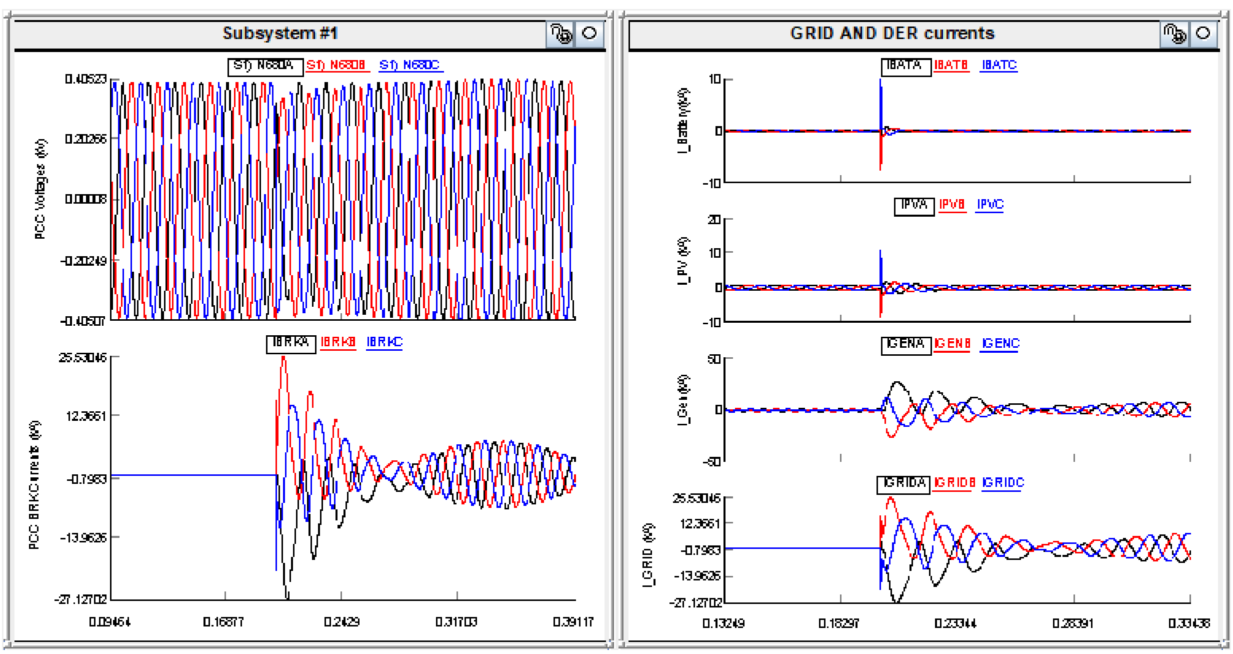


(b)

In island mode, the PV, Battery and Generator supply the load



(c)



(d)

Fig23 (a) Runtime model of a portion of the 9 bus model, (b) Electrical Signals in normal condition before islanding/ fault injection, (c) Signals during islanded mode of operation, (d) after fault clearance, signals trying to resynchronize with the main utility grid

6.2 Reinforcement Learning Accuracy

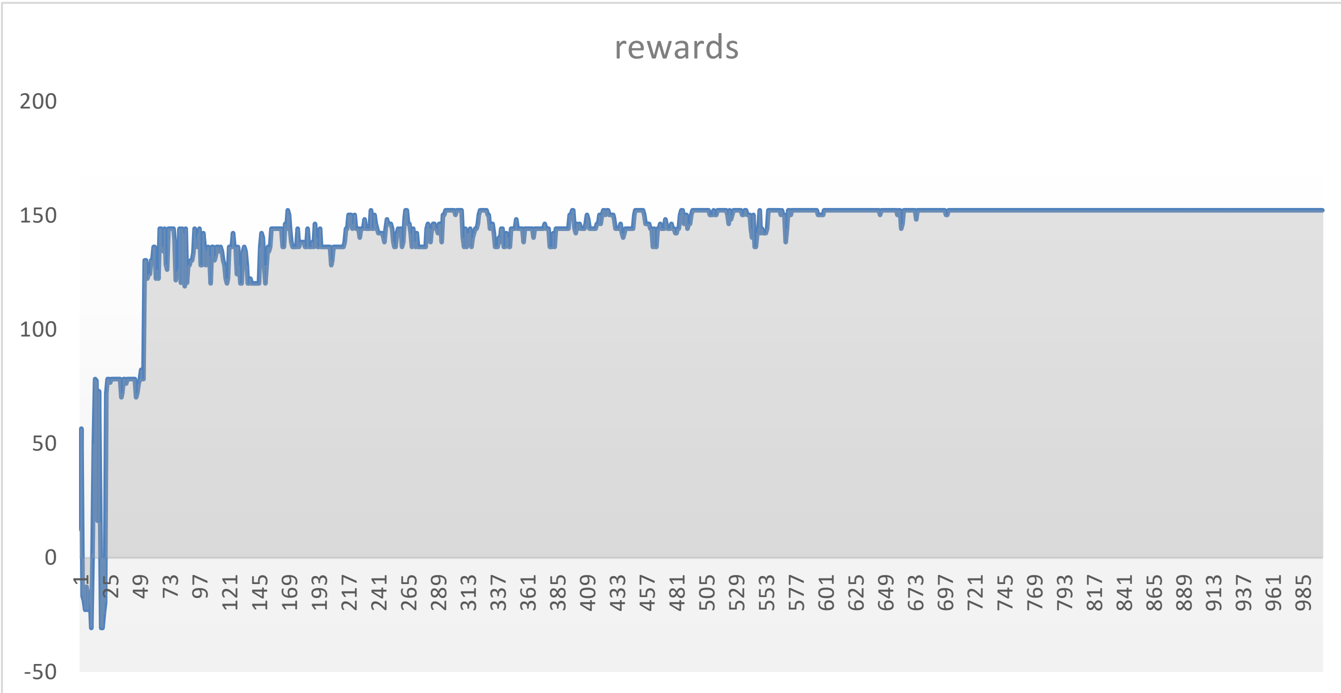


Fig24 Rewards achieved during training of Advantage Actor-Critic Model over time

	precision	recall	f1-score
0	0.97	1.00	0.99
1	1.00	0.93	0.96
accuracy			0.98
macro avg	0.99	0.96	0.97
weighted avg	0.98	0.98	0.98

	precision	recall	f1-score
0	0.97	1.00	0.99
1	1.00	0.93	0.96
accuracy			0.98
macro avg	0.99	0.96	0.97
weighted avg	0.98	0.98	0.98

Fig25 Training and Test Results

6.3 Discussion

1. First of all, the runtime model is made to run. Initially the DERs are connected and the load is supplied by both the micro grid and the utility grid. In Fig a) the battery is set to discharge (Pref = +0.5) and the excess power is sent to the grid. Receiving power by any source is provided with a minus sign, while sending power is administered with a positive sign. Next the state of charge (SOC) of the battery is observed. If it falls below 50%, then PREF value is set to -0.5 for pushing it to charging mode. But overall, there would be no such disturbance shown in the signals as long as synchronized operation takes place.

2. Next cause a fault to happen by pressing the push button switch. (The change in color of the spark sign denotes it) It will come into observation that the Square representing CB will also turn red representing the disconnection of the main utility grid. This can be noticed from Fig b) which shows the current in the main circuit breaker as well as the grid turning to zero. At the same time the diesel generator present tries to compensate and feed the load with the sufficient power that the main grid was providing. Hence an increase in the overall current signal of the circuit breaker is shown.

3. Now, as a temporary fault was forced to happen, it gets cleared after sometime; and the reclose signal from the relay is sent to the circuit breaker. The circuit breaker recloses and checks whether the fault persists or not. As it happens to see the fault to be recleared; it tries to synchronize the signals with the other generators operating and helps in continual flow power to the load. In Fig c), how the signals try to resynchronize is shown, after which it returns to the state shown by Fig a).

6.4 Future Scope

Coming to the future scope of the research, which the main aim is; behind studying all such results and observations, have a much broader aspect.

There are two ways in which a relay can get disturbed signals. One being the situation when really fault has occurred and the other when cyber criminals feed in wrong data to the CTs and PTs thus manipulating the original data and providing an erroneous data to the relay. Now anticipating the relay operation, if it acts just according to the CT and PT adjoint to the relay and send a trip signal to the circuit breaker then the outcome obtained may not be a completely gratifying one, hence implementing a wrong decision which may thwart the smooth run of a particular EPS. Hence the main reason behind studying the PMU data received is to form a trend that could be fed to the relay depending on which it would make decisions. This is because if an invader is able to manipulate a single PMU data, then hopefully the other PMUs acting when a fault has occurred would provide with correct result. Now getting out the trend that the PMUs follow when a fault occurs is the main area of research since cyber protection comes along with the need to make the grid smarter through different communication channels.

References:

1. https://www.sciencedirect.com
2. https://ieeexplore.ieee.org
3. https://www.weatheronline.in/
4. https://www.wunderground.com/weather/in/new-delhi
5. https://www.worldweatheronline.com/
6. https://www.timeanddate.com/weather/india/dhanbad/ext
7. http://cea.nic.in/monthlyarchive.html